TECHNICAL MEMORANDUMS

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

No. 345

PHOTOGRAPHIC TIME STUDIES OF AIRPLANE PATHS

By A. G. Von Baumhauer

"Report V 79" from "Verslagen en Verhandelingen van den Rijks-Studiedienst voor de Luchtvaart," Part III, 1925.

Washington
January, 1926

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

TECHNICAL MEMORANDUM NO. 345.

PHOTOGRAPHIC TIME STUDIES OF AIRPLANE PATHS.*

By A. G. Von Baumhauer.

The object of this report is the description of a method tested by the R. S. L. (Rijks-Studiedienst voor de Luchtvaart), which seems to be practicable for determining the path of an airplane, especially in taking off and in landing. This report tells how, by means of a photograph camera, preferably a kinetograph, which simultaneously photographs a stop watch the distance of an airplane from the camera and its height above the ground, can be determined. For this purpose, we must know the span of the airplane and the focal length of the camera lens. The airplane must fly either with or against the wind directly over the camera. Various applications, including the determination of the take-off distance, are described. A method for determining the velocity is also described. With the help of these methods, various data can be obtained with a fair degree of accuracy, for which there is no other satisfactory method. In judging an airplane, it is very important to know its behavior in taking off and in landing.

For the safety of commercial airplanes, there are government stipulations** regarding the altitude an airplane must

* "Report V 79" from "Verslagen en Verhandelingen van den Rijks-Studiedienst voor de Luchtvaart," Part III, 1925, pp. 101-108, reprinted from "De Ingenieur," of January 26, 1924.
** Ministerial decree of the "Waterstaat" (Department of Dikes, Waterways and Roads), May 28, 1924.

reach within a certain distance from the starting point (e.g., at least 20 meters (65.6 feet) within a distance of 650 m (2132.5 ft.)). Moreover, it is useful to know the flight speed (e.g., in landing), the climbing speed near the ground, etc. It is therefore important to know the path followed by the airplane and the time taken to reach the different points in this path. This seems to be possible with the aid of the following methods.

In the changing motion, both in climbing and in landing, existing altimeters and speedometers cannot be relied on. Barometric altimeters, in fact, are accurate only to within a few meters, which are here of considerable importance. The elastic reaction of the aneroid box causes perceptible deviations in the position of its needle. It should be possible to find the distances by integrating the changing speed according to the time. Windmill speedometers would be retarded by their inertia. The membrane indicators of manometric or pressure speedometers are not sufficiently accurate, due to the elastic reaction.

The method is based on the possibility of determining the distance between the camera and the airplane from the size of the latter's image on a photograph, when the focal length of the camera and the span of the airplane are known. In order to simplify the matter, care is taken to keep the path of the airplane in a vertical plane (passing through the camera) parallel with the wind. This accords with the practical requirement that the airplane must face the wind in taking off and in landing.

The camera is placed with its optical axis in the direction of the wind and the pilot is instructed to fly in this "wind-plane" during the test (Fig. 1). The plane of symmetry of the airplane is kept as much as possible in the wind-plane passing through the camera. The wings are thus photographed "unshortened." In these tests, the actual span of the airplane is measured and also the span of its image on the photograph. From the ratio thus obtained and the accurately-known focal length of the lens, the distance between the camera and the airplane can then be calculated. The lens is focused at infinity.

Let L denote distance of airplane; B, span of airplane; f, focal length of lens; b, span of airplane image. It then follows from Fig. 2, that $L : B = f : b$. Since B, F and b are known, L can be calculated. If, for example, $B = 12.5$ m (41 ft.), $f = 50$ mm (1.97 in.) and $b = 2.5$ mm (.098 in.), then $L = 250$ m (820 ft.).

The altitude of the airplane can also be determined from the photograph. The vertical line, from the airplane to the ground, lies in the same vertical plane as the airplane, this vertical plane being parallel to the photographic negative. The altitude is therefore diminished on the negative in the same ratio as the wing span. The altitude h and the span b are measured on the photograph (Fig. 3). Then $H : h = B : b$ and $H = \frac{hB}{b}$, which is the real altitude of the airplane.

In order to determine the times and speeds, the instants of exposure of the photographic film must be accurately known. In this use of the photographic camera with stationary film pack, the exposures are made at the instants when the photographer sees the second-hand pass predetermined points, e.g., at 10, 13, 16, 20, 25, 30, 40 and 50 seconds after the start of a commercial airplane. Three cameras are used, in order to allow time for changing the films.

An accurate time record is obtained by the simultaneous photographing of a stop watch, a device for this purpose being attached to a kinetograph. In order to avoid the necessity of changing the camera internally and thus rendering it less suitable for other work, the stop watch is fitted to it externally and photographed by means of a concave mirror, as shown in Fig. 4. The stop watch is placed at the focus of a hollow mirror which is mounted in front of the lens of the kinetograph, the latter being focused at infinity. The image formed of the watch is one-tenth of its actual size, since the ratio of the focal lengths of the mirror and of the camera lens is 500 : 50 = 10. The photographic reproduction of this image occupies a circle of about 5 mm (0.2 in.) diameter in the lower right-hand corner of the 18 x 24 mm (0.71 x 0.94 in.) photograph.

The mirror is mounted on the camera support and the watch on the camera itself, both being easily removable. For transportation, the mirror and its support are packed in a small case 4.5 × 6.5 × 65 cm (1.8 × 2.6 × 26 in.) and the watch is carried inverted on the camera. Altogether the extra weight is nearly 1 kg (2.2 lb.). The mirror is a spectacle-glass having a focal length of 2 m (6.56 ft.), with one side silvered. In front of the camera lens, having a focal length of 80 or 150 mm (3.15 or 5.91 in.), there are devices whereby a secondary system projects the image of the watch on to the film, with the aid of a prism placed between the film and the lens. With a kinetograph, a complete series of pictures can be obtained, showing all the special points, e.g., the first contact with the ground in landing, etc. In order not to have too many pictures to be developed and to save film, a special adjustment can be made, so as to take about two pictures a second, instead of the usual number of 15-18. The exposure can be made short enough by increasing the size of the aperture.

In taking off, the film records, with a fair degree of accuracy, the instant of leaving the ground. In order, however, to determine from the photograph the distance taxied, use is made of the time as found directly with the aid of a stop watch. This method has been verified and found to be reliable by direct measurement on the ground.

Judging the errors.- For measuring the photographs, the

R.S.L. used a Leitz measuring microscope suited for plates not larger than 13 × 18 cm (about 5.1 × 7.1 in.). For images larger than 5 mm (0.2 in.), the measuring is done on double vertical scales with verniers to 0.05 mm (0.002 in.). Smaller images are measured with an ocular micrometer, whereby the accuracy limit is set by the fineness of the photographic material and the sharpness of the definition, that is, at 0.02 mm (0.0008 in.). If the error in measuring the size of the image is Δb, the error in the actual distance is ΔL. $\frac{\Delta L}{L} = \frac{-\Delta b}{b}$. On replacing b by its value $\frac{fB}{L}$, we obtain $\Delta L = -\Delta b \times \frac{L^2}{fB}$.

The absolute error in the distance is inversely proportional to the focal length and directly proportional to the square of the distance.* For a certain maximum error in the measurement of the image, the necessary focal length can be calculated for the given conditions and a certain admissible error in the distance. The following example will illustrate.

The span $B = 12.5$ m (41 ft.); distance $L = 500$ m (1640 ft.); error in measurement of image $\Delta b = 0.02$ mm (0.0008 in.). With a focal length $f = 50$ mm (1.97 in.), the calculated error in the distance is 8 m (26 ft.). This focal length is utilized in the Ernemann kinetograph, with which various experiments of this kind have been tried. With this camera, successive exposures can be rapidly made. In plotting the path

* This applies also to the two-glass telemeter. In comparisons, the span of the airplane is taken as the basis of measurement. The size of the image is the unit of measurement for the parallax.

through the special points, only a small mean error is made.

For the accurate determination of speeds, etc., at greater distances, a lens with a greater focal length must be used. With $f = 720$ mm (28.35 in.) and $B = 12.5$ m (41 ft.), the relative error at 1500 m (nearly 5000 ft.) is only 1/3%. If great accuracy is desired, some object of known size and distance can be included in the photograph for the sake of comparison.

Errors due to the camera have little or no effect on the accuracy of the altitude measurements, since the height and width are both affected alike thereby. For determining the altitude, the distance must be measured on the photograph from some part of the airplane to the horizon. As a rule, the horizon is not sharply defined on the photograph. In practice, the horizon was successfully replaced by the horizontal plane passing through the lens. A point is then taken on some object (e.g., a house) or person in the background, which point is at about the same level as the lens, while on the airplane some point is selected which is as nearly as possible at the same level when the airplane is on the ground (Fig. 3).

As regards the timing, the accuracy depends on the timepiece used and the size of the divisions. Readings can be accurately made to 1/5 second on a watch having a dial 50 mm (about 2 in.) in diameter with a revolution period of 30 sec.

Fig. 5 records the measurements made on photographs taken during the start of an observation airplane. Both horizontal distance and altitude are here plotted against the time. The scattering of the points is very slight, even at a long distance. The climbing speed became practically constant shortly after the airplane left the ground. The following results were obtained: length of ground run, 104 m (341 ft.); time taken for run, 8.7 sec.; distance flown during 16th to 25th second inclusive, 240 m (787 ft.); mean speed, 24 m (78.7 ft.) per second. The velocity of the wind being 7.5 m (24.6 ft.) per second, the speed of the airplane was therefore 24 + 7.5 = 31.5 m (103.3 ft.) per second or 113 km (70.2 miles) per hour. At 300 m (984 ft.) from the starting point, the altitude was 38.5 m (126.3 ft.). At this point the climbing speed was 6.2 m (20.3 ft.) per second.

The photographic method is preferable for measuring the take-off and landing runs of seaplanes, since these distances cannot be measured with a tape, as in the case of land airplanes.

As one of the accomplishments of the photographic method, we can also report the measurement of the maximum speed of an airplane from the ground. The usual method of determining the speed of an airplane is to eliminate the velocity of the wind by flying along the sides of a triangle. If the path of the airplane happens to be in the direction of the wind, it is only necessary to fly over the same route in opposite directions. This seldom happens with fixed landmarks, but can be obtained at will by the photographic method, the airplane having only to fly over the camera both with and against the wind.

The fact that the altitude can be determined with sufficient accuracy for several kilometers before the beginning of and during the course, furnishes a good control of the so-called "steken" (i.e., the diving before and during the course) for the purpose of unfairly increasing the speed. Whenever the aviators know that the altitude is prescribed, they should refrain from this trick.

With a great enough focal length, f = 720 mm (28.35 in.), a course of 3000 m (nearly 10,000 ft.) can be covered, i.e., 1500 m (nearly 5000 ft.) from the camera in each direction. By taking several photographs at the distance of about 1500 m, the effect of the errors can be lessened by taking the mean result in the graphic representation. In this measurement, it is desirable, for the sake of comparison, to include in the photographs objects of known dimensions and at about the same distance (e.g., 1500 m).

Since great accuracy is required, a watch whose second-hand revolves once in three seconds can be employed. The exposure time of 1/60 second would give a blurred image of the hand at a higher revolution speed. In this way, the time can be read from the image to 1/100 second.

I think the above-described method will meet the requirements of the International Aeronautic Federation for measuring the maximum speed of airplanes from the ground.

In conclusion, it may be remarked that this method can perhaps be utilized in other fields, e.g., to determine the speed of ships. In the latter case, the kinetograph can be placed on board, in order to photograph landmarks whose distance is known.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.

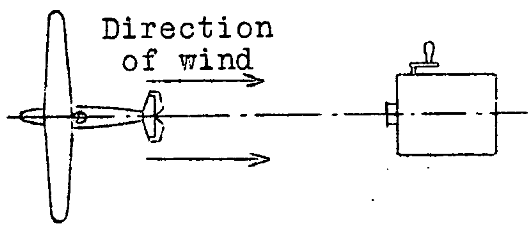

Fig.1

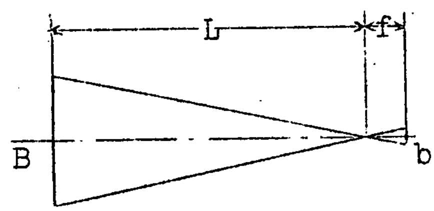

Fig.2

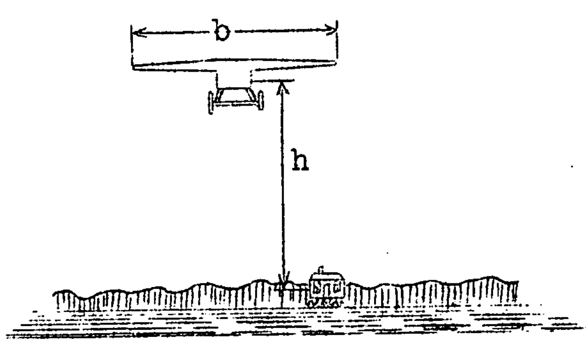

Fig.3

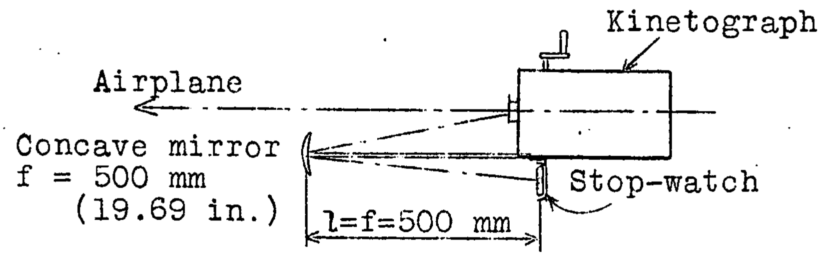

Fig.4

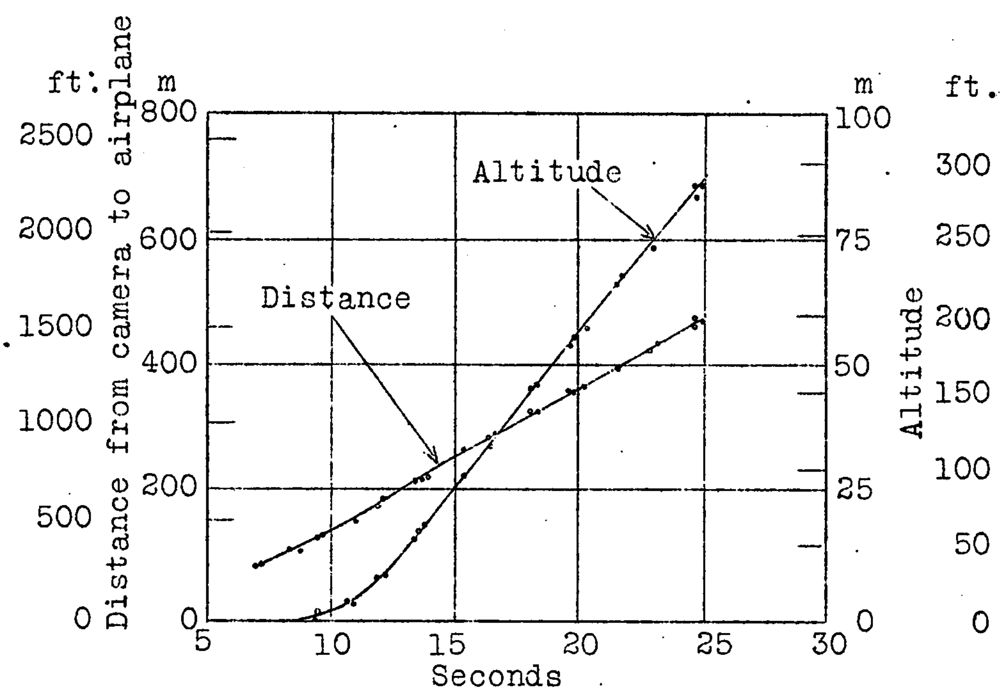

Fig.5 Climbing time